Electric field Systematic Study Report

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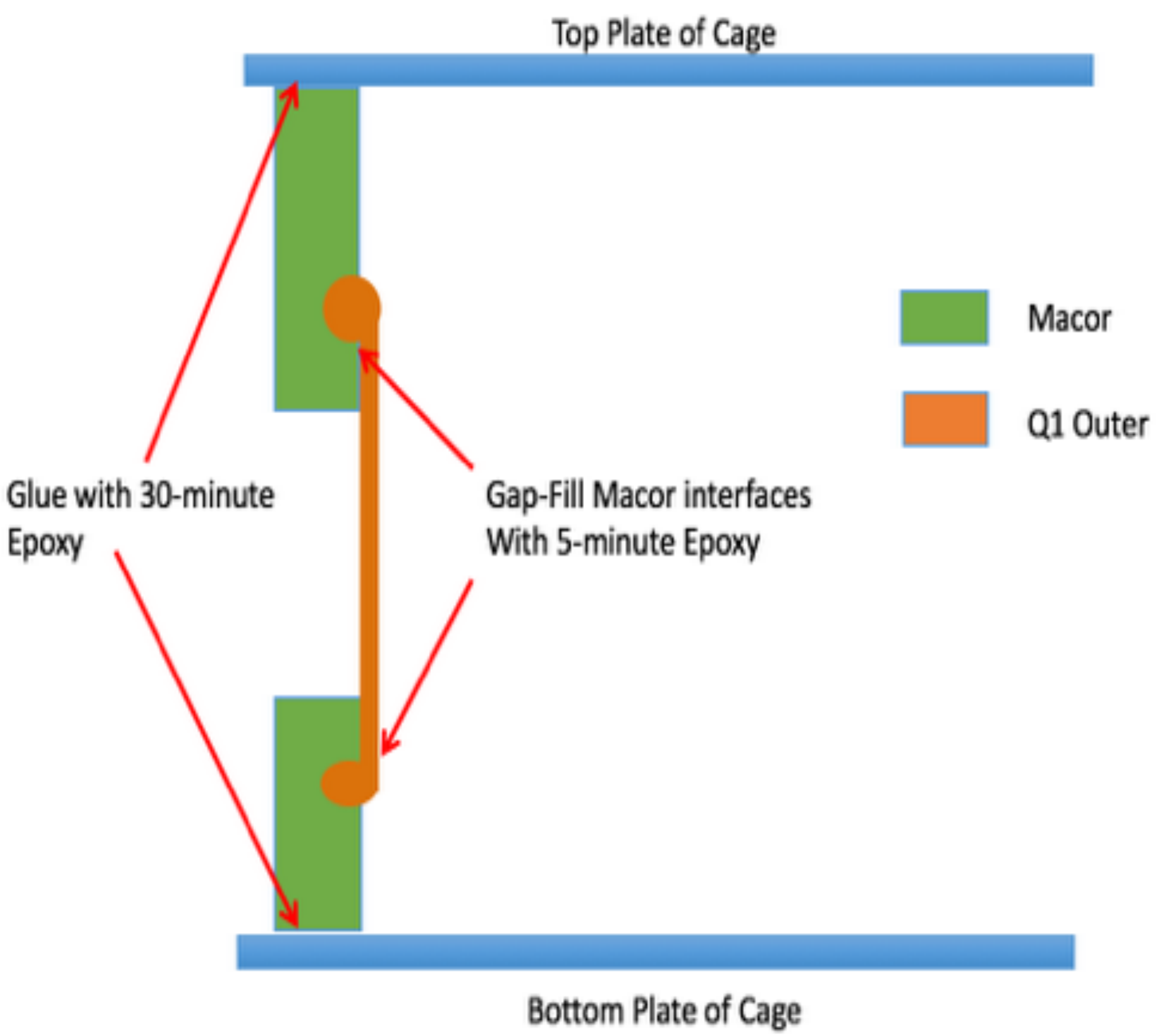
Beam/Spin Dynamics Systematic Error Workshop
Nov. 30, 2016

Outline

- **Quad Plate Alignment**
  - Q1 outer alignment
  - status and summary
- **Electric Field Map**
  - 2D E field map
  - 3D E field map
- **Fast Rotation Analysis**
  - things to do

Quad Plate Alignment — Q1 outer plate

No screws!!

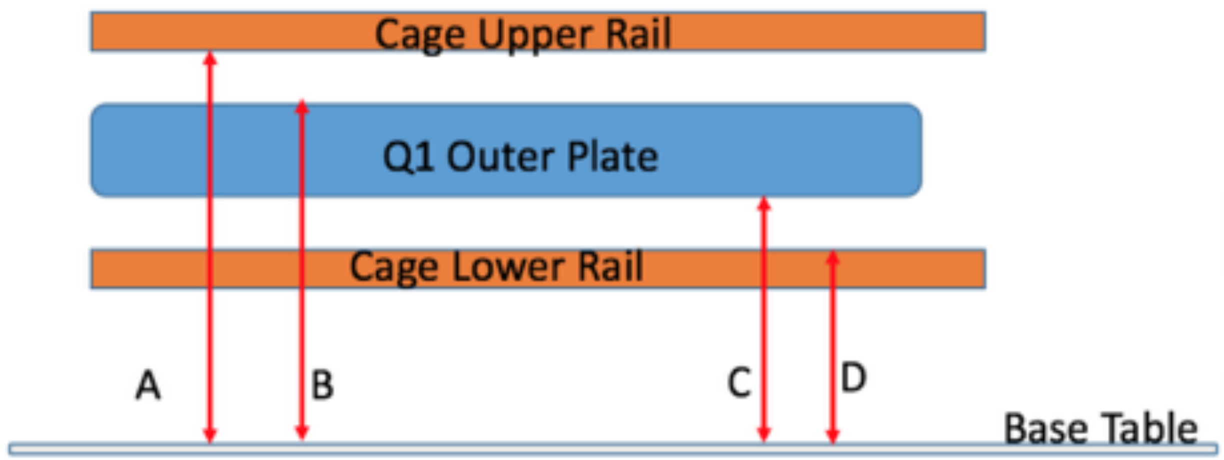


see: docdb=4542 and hogan's talk

Quad Plate Alignment — Q1 outer plate

A large gap

Because the standoffs for q1 outer plate are short, we need do the vertical alignment.



For Q1 outer plate vertical alignment, we use the distances between cage rails and plate edges.

$$\text{Distance\_1} = A - B \quad (= A' - B' + L)$$

$$\text{Distance\_2} = C - D \quad (= C' - D' + L)$$

Here, A', B', C' and D' are modified distances; L is the width of the arm of the standing caliper.

$$A' = A - L; \quad B' = B$$

$$C' = C - L; \quad D' = D$$

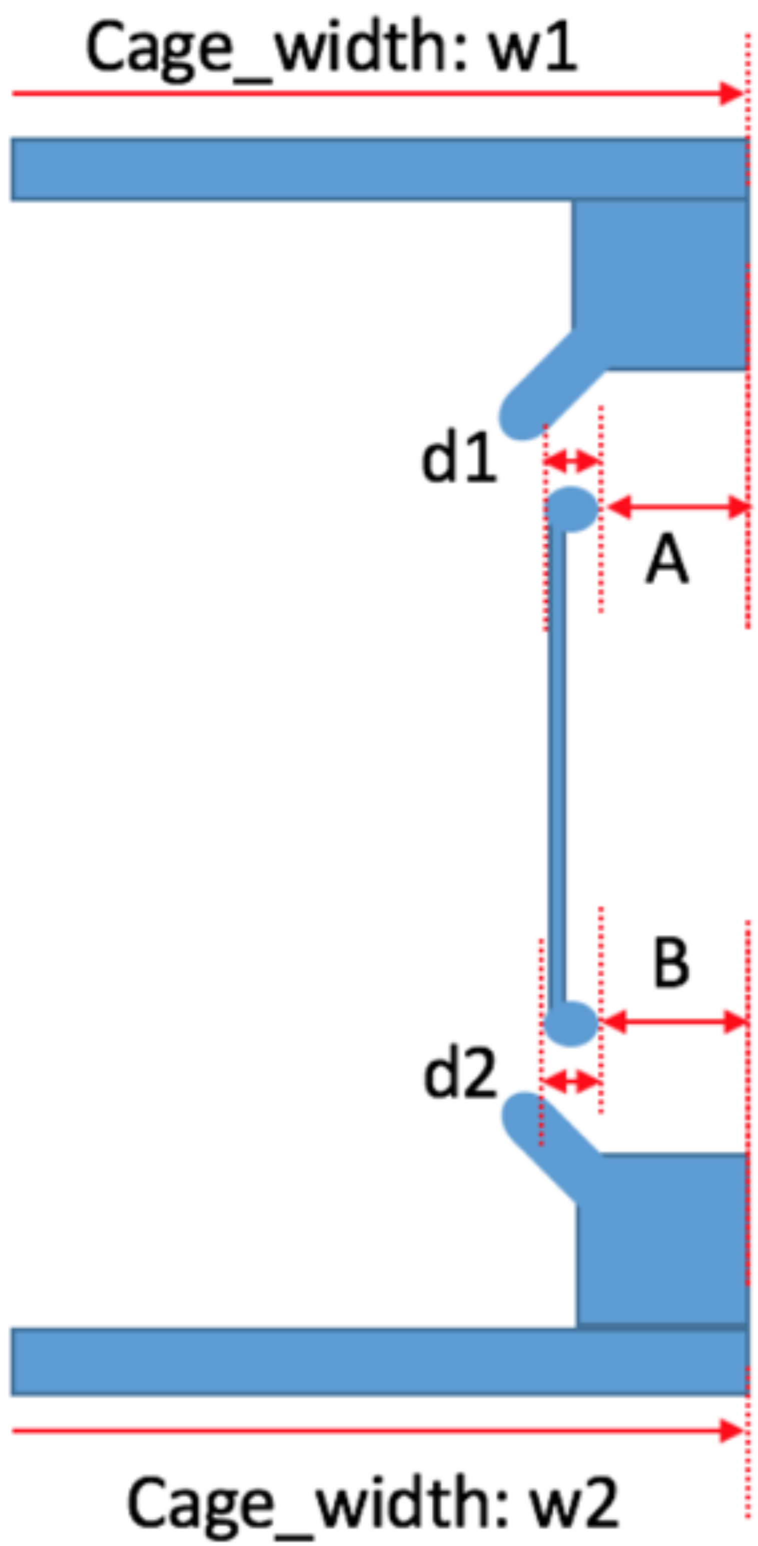
We measure:

$$\text{Distance\_1}' = A' - B'$$

$$\text{Distance\_2}' = C' - D'$$

Result: less than ± 0.2 mm

Quad Plate Alignment — Q1 outer plate



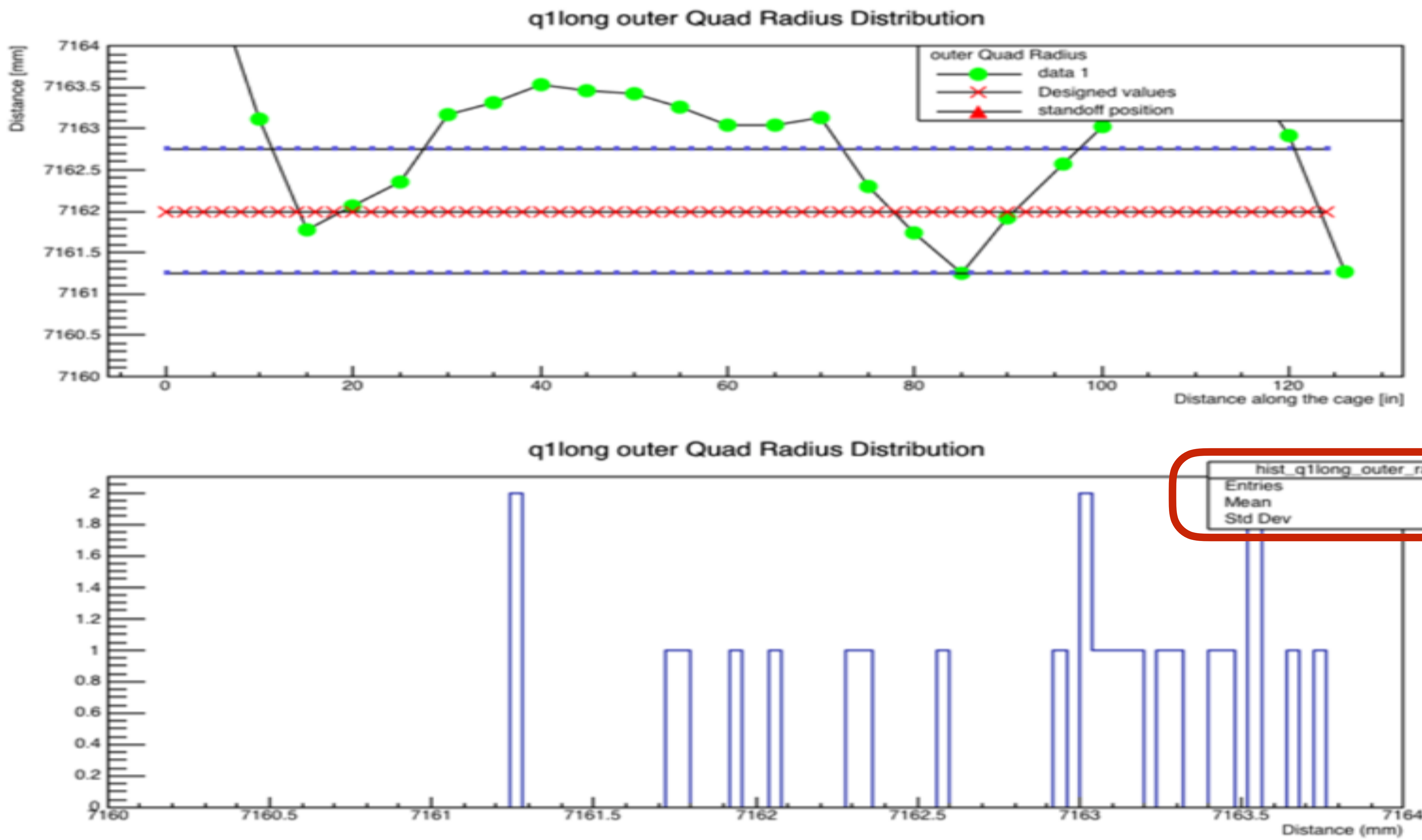
<u>Q1 out plate horizontal alignment (before the standoffs were glued)</u>

We measure A, B, w1, w2, d1, and d2:
The radius of the plate can be given:

Radius_1 = 7112 + w1/2 – A – d1
Radius_2 = 7112 + w2/2 – B – d2
Radius = (Radius_1 + Radius_2)/2

Because we want to maintain a flat Mylar surface, we cannot add azimuthal force (along the cage) to the standoff.

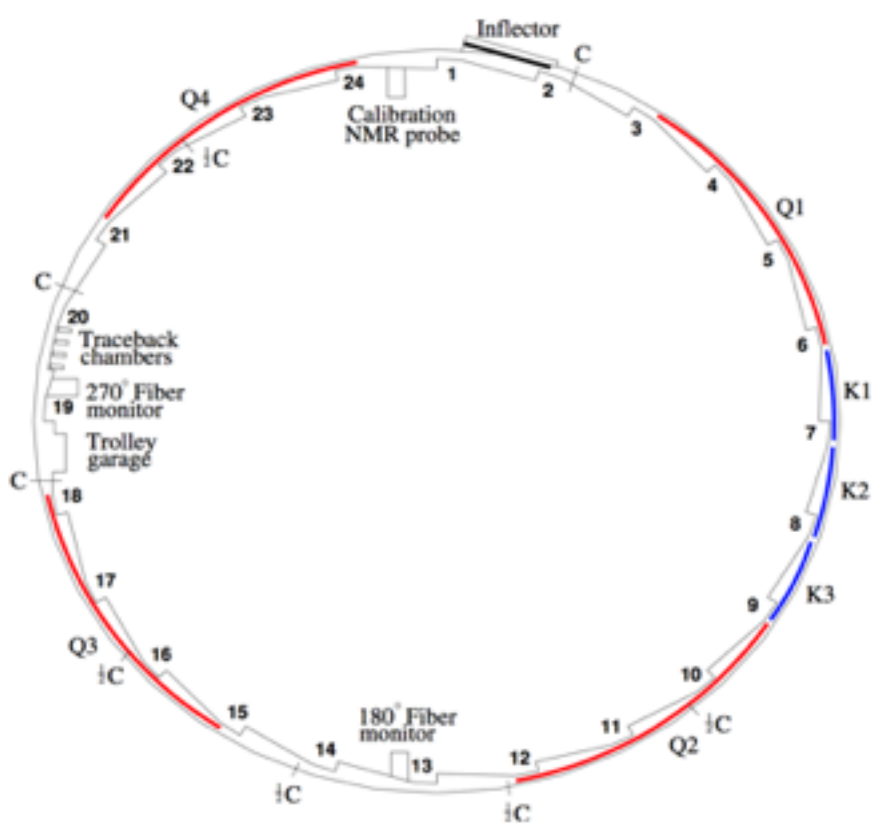
Quad Plate Alignment — Q1 outer plate



This is an averaged result! There is also an effect of “waviness” of Q1 Mylar.

See hogan’s talk…

Quad Plate Alignment — Status and Summary



Cage	Micrometer tool Alignment	Laser System Scan
Q1 Long		
Q1 Short		
Q2 Long		
Q2 Short		
Q3 Long		
Q3 Short		
Q4 Long		
Q4 Short		

Done

ToDo

Almost done! Executing physical study.

Other reference: see docdb=4116

Electric Field Map— 2D v.s. 3D

- We need to know the electric field: the E-field corrections, muon tracking, CBOs, HV sparking etc.
- We don't measure the electric field inside the storage ring.
- We can get the electric field map from simulation or fitting a Laplace's equation.
- E821 only had 2D E-field map, i.e., from OPERA 2D or SIMION(see NIM quad paper 2003).
- We want a 3D E-field map to study the systematic errors.

Suppose the z axis has a radius of curvature $\rho = \rho(z)$, or curvature $h = \rho^{-1}$. Then Laplace's equation has the form

$$\nabla^2 V = \frac{1}{1+hx}\frac{\partial}{\partial x}\left((1+hx)\frac{\partial V}{\partial x}\right) + \frac{\partial^2 V}{\partial y^2} + \frac{1}{1+hx}\frac{\partial}{\partial z}\left(\frac{1}{1+hx}\frac{\partial V}{\partial z}\right) = 0. \tag{3.1}$$

$$\boxed{E = -\nabla V}$$

Electric Field Map—2D v.s. 3D

Y.K. Semertzidis et al. / Nuclear Instruments and Methods in Physics Research A 503 (2003) 458–484

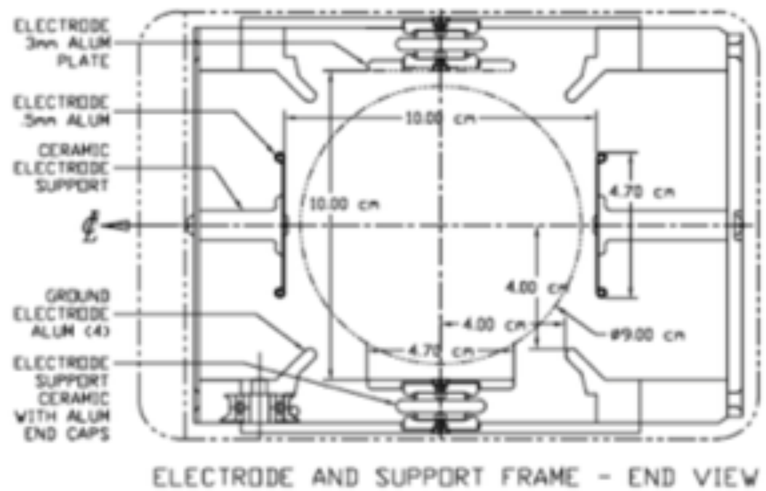
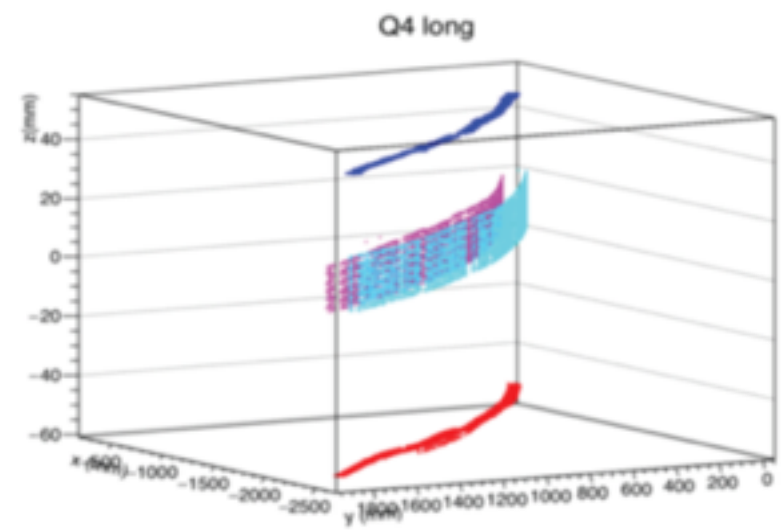
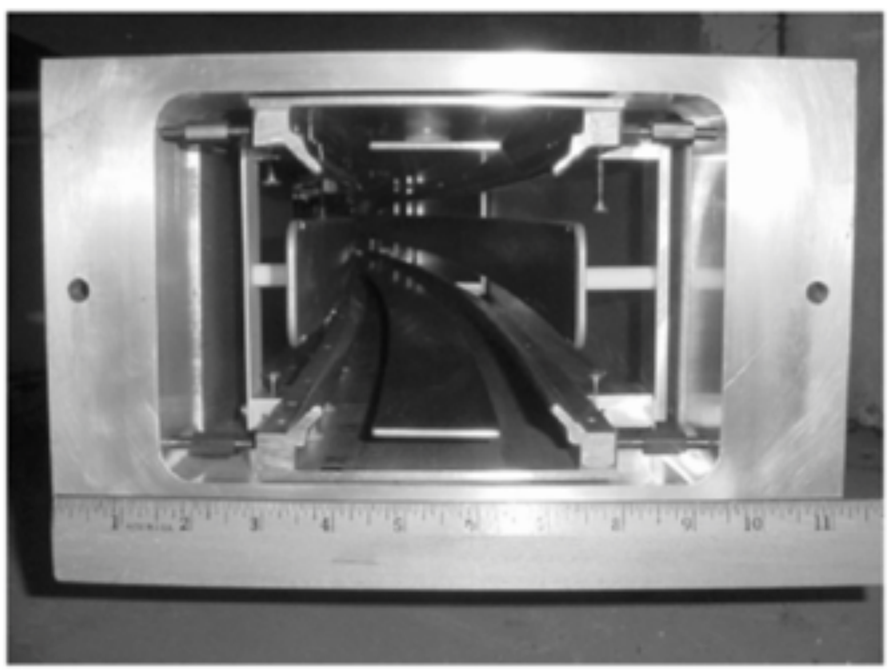
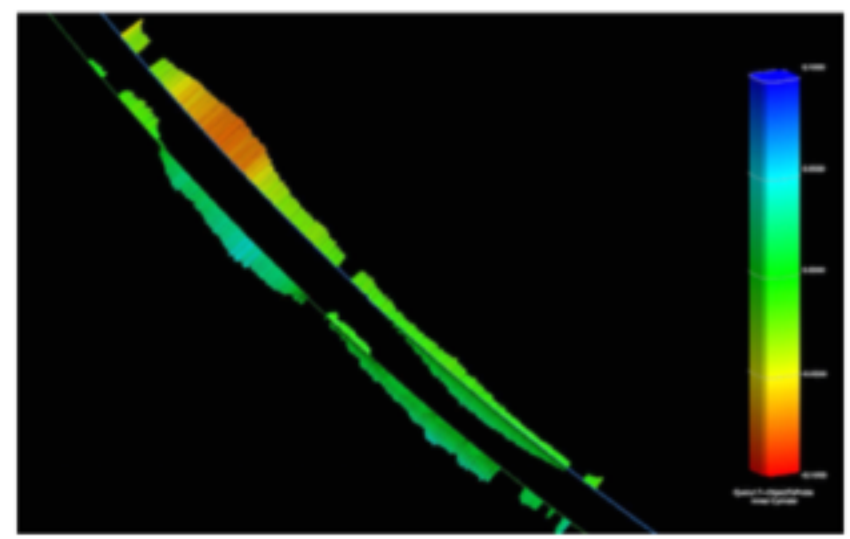


Fig. 5. The cross section of the quadrupole plates ("electrodes") and NMR trolley rails ("ground electrodes"). The top-bottom a as the left-right high voltage support insulators are also shown.

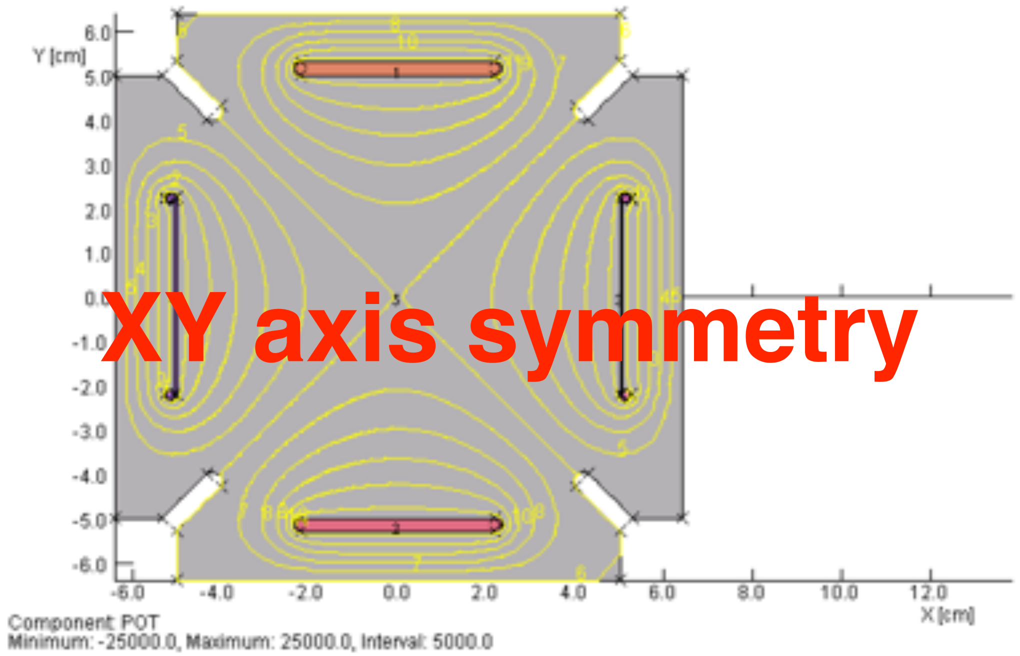


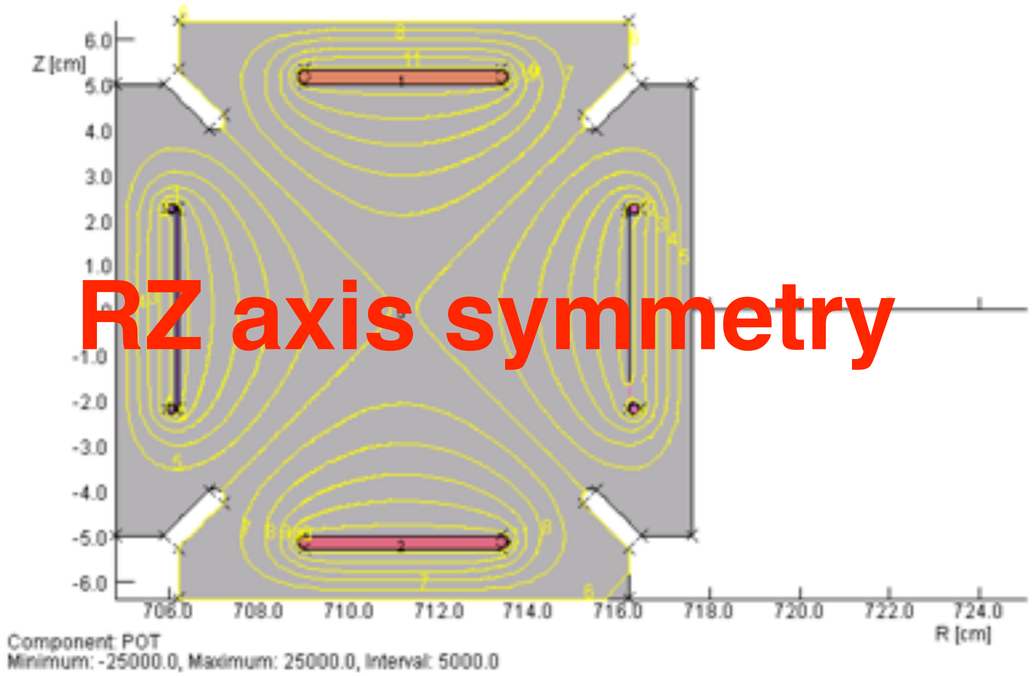


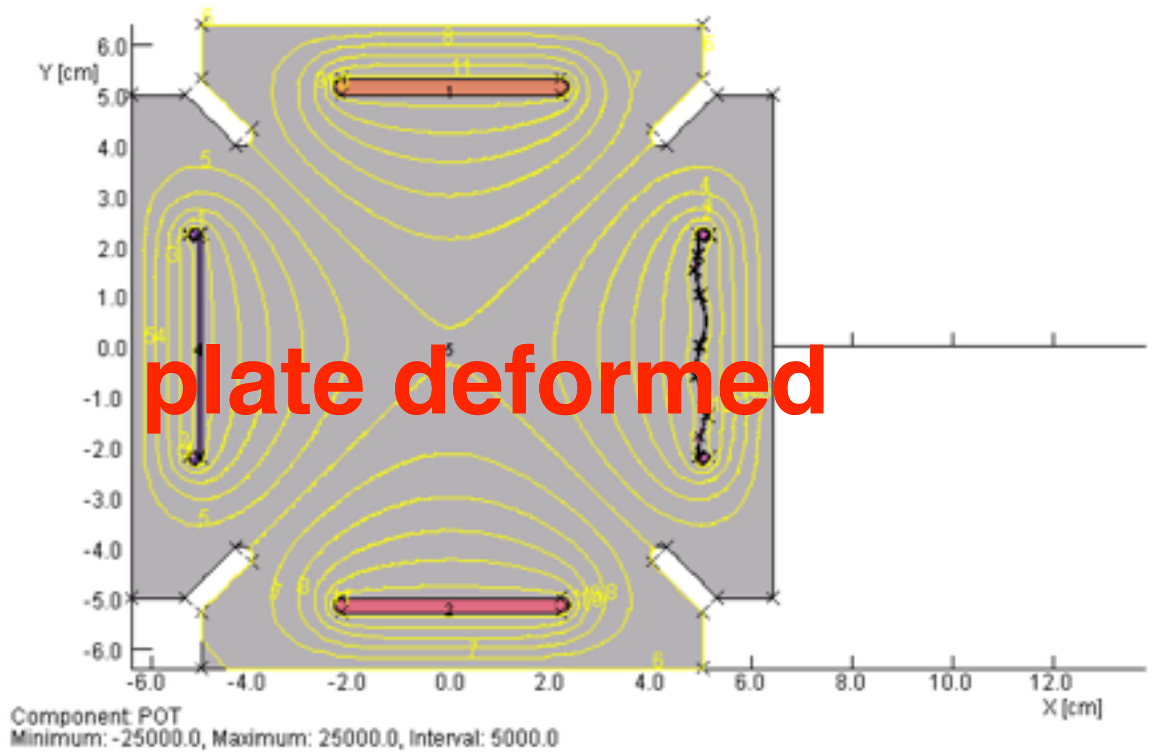


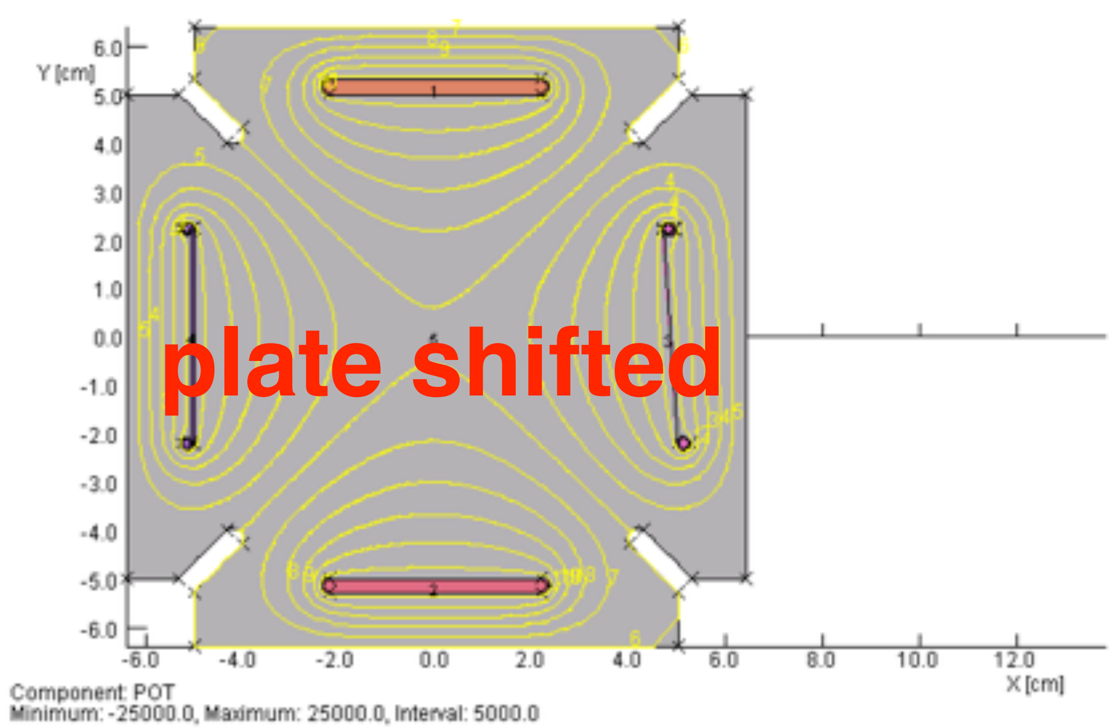
Can we have a more practical field map from the geometry we know?

Electric Field Map—2D from OPERA 2D



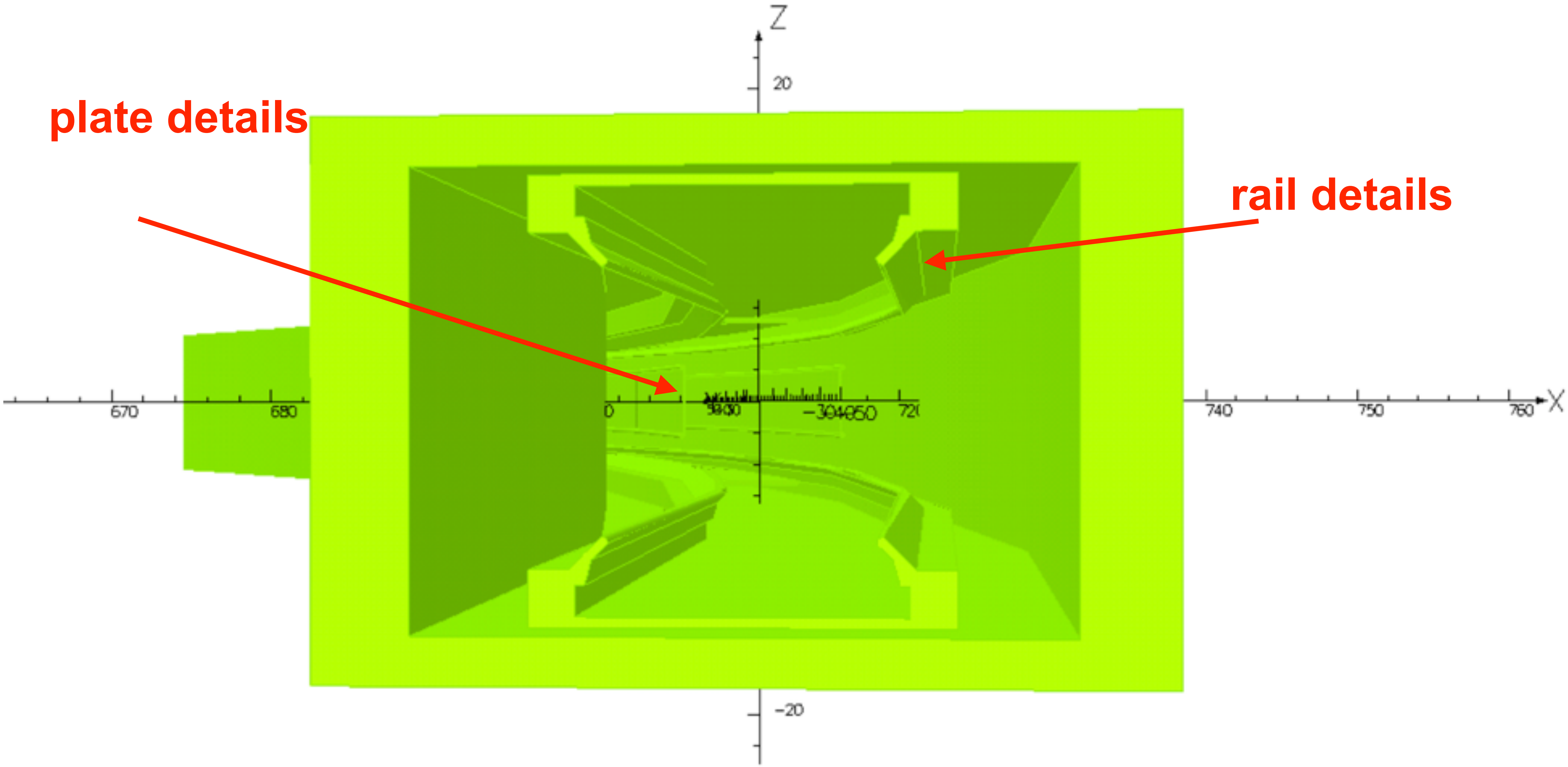






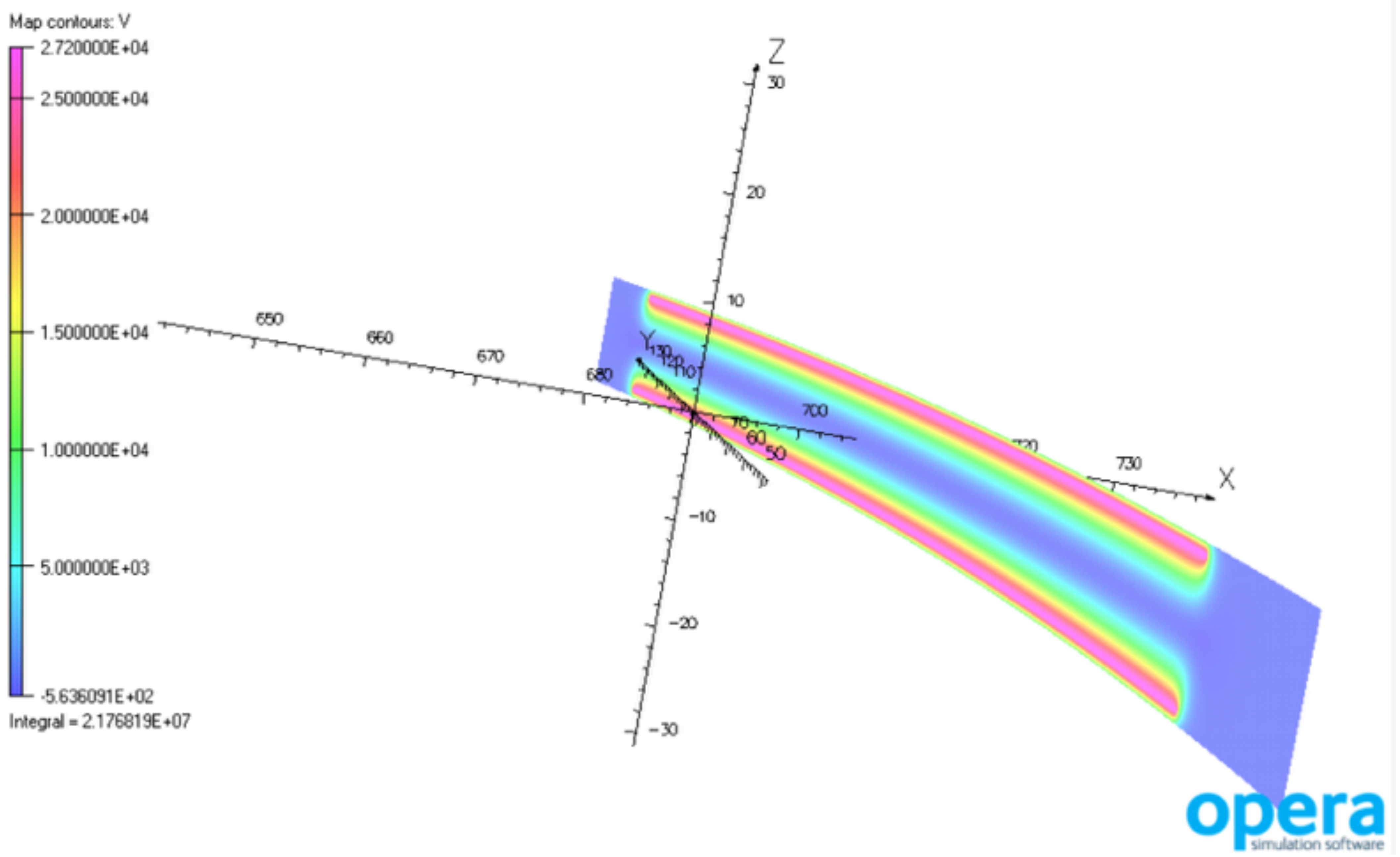
(see hogan's talk)

Electric Field Map—3D from OPERA 3D



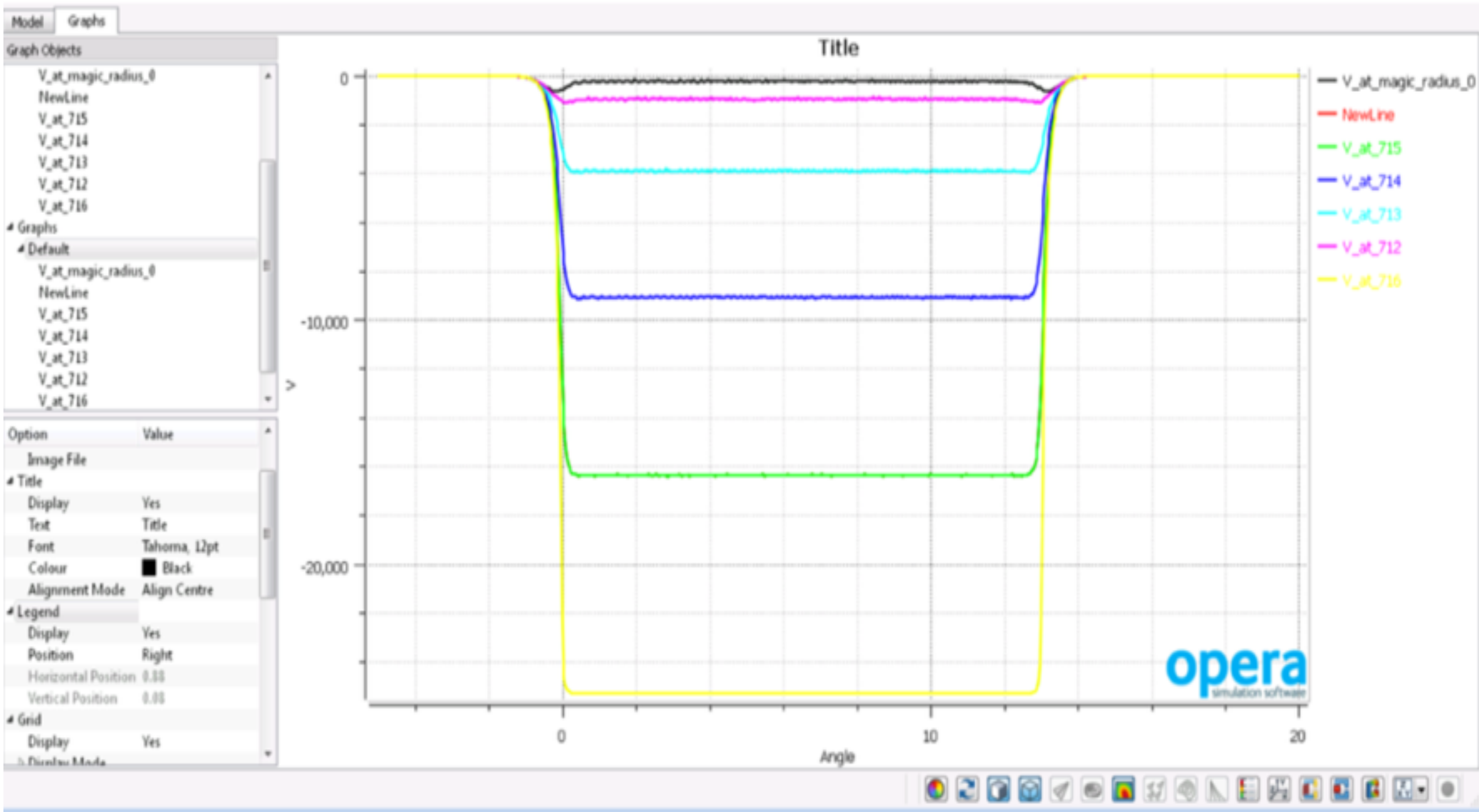
Model: short plates inside a ‘long’ cage and chamber

Electric Field Map—3D from OPERA 3D



Electric Potential at some plane (cylinder surface with magic radius)

Electric Field Map—3D from OPERA 3D



Electric Potential at circle with different radius

Electric Field Map—3D from OPERA 3D

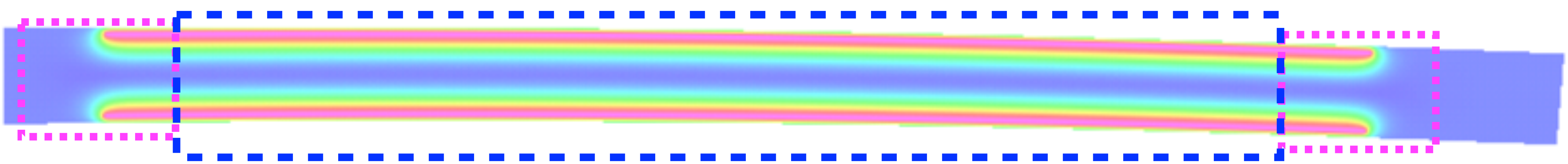
Our field data on cylinder grid:

Data is very large (> 10 GB)

output_designed_27k2_all_cylinder_endDS.txt

R	Theta	Z	Er	Etheta	Ez	E_mag	V
7.013999999999999773e+02	1.745329251992046304e-02	6.400000000000000355e+00	2.447911947398412451e+02	2.100470627610892649e+00	-1.011787863259999938e+02	2.648854239130000110e+02	-4.731656481990000174e+01
7.013999999999999773e+02	-1.745329251992046304e-02	6.400000000000000355e+00	1.208368570590862445e+00	1.233312347824337407e-01	-5.478908312579999773e-01	1.332497489240000110e+00	-2.469954867839999901e-01
7.013999999999999773e+02	1.727788254492839889e-02	6.400000000000000355e+00	2.452150776529214795e+02	1.195175950826990352e+00	-9.868162054500000124e+01	2.643291981360000023e+02	-4.783092442390000087e+01
7.013999999999999773e+02	-1.727788254492839889e-02	6.400000000000000355e+00	1.261539827282873505e+00	1.331830903609285133e-01	-5.789424977199999489e-01	1.394415607710000060e+00	-2.558336872900000003e-01
7.013999999999999773e+02	1.710247256973554744e-02	6.400000000000000355e+00	2.462368232089528419e+02	-9.093377510984068657e-01	-1.016478866439999962e+02	2.663938679070000148e+02	-4.632896942480000035e+01
7.013999999999999773e+02	-1.710247256973554744e-02	6.400000000000000355e+00	1.316461810404460975e+00	1.370614452123015692e-01	-5.865352030949999573e-01	1.447715815510000059e+00	-2.537837872190000232e-01
7.013999999999999773e+02	1.692706259476520897e-02	6.400000000000000355e+00	2.461029913986091344e+02	-3.017913522167438245e+00	-1.075479585780000065e+02	2.685932865350000043e+02	-4.529972215400000124e+01
7.013999999999999773e+02	-1.692706259476520897e-02	6.400000000000000355e+00	1.419163179113325235e+00	1.380737603822703163e-01	-5.716590752800000397e-01	1.536190935590000084e+00	-2.708621724420000043e-01
7.013999999999999773e+02	1.675165261965807367e-02	6.400000000000000355e+00	2.442051364415897581e+02	-1.687829328620356950e+00	-1.120068833330000047e+02	2.686718060129999799e+02	-4.661691523849999896e+01
7.013999999999999773e+02	-1.675165261965807367e-02	6.400000000000000355e+00	1.520315462750068347e+00	1.436604458327009892e-01	-5.762160872439999748e-01	1.632183325850000033e+00	-2.889914657389999753e-01
7.013999999999999773e+02	1.657624264455220126e-02	6.400000000000000355e+00	2.421157042407676556e+02	1.512285961893787167e+00	-1.100235643660000022e+02	2.659463967880000155e+02	-4.679165347810000242e+01
7.013999999999999773e+02	-1.657624264455220126e-02	6.400000000000000355e+00	1.612945903592825303e+00	1.662056384094273698e-01	-6.420940746690000367e-01	1.743990711809999983e+00	-3.017932309940000168e-01
7.013999999999999773e+02	1.640083266946756185e-02	6.400000000000000355e+00	2.413473946027515069e+02	1.969673233490970787e+00	-1.116014995200000044e+02	2.659085165789999792e+02	-4.692503394149999707e+01
7.013999999999999773e+02	-1.640083266946756185e-02	6.400000000000000355e+00	1.690190165915212983e+00	1.937178380437598602e-01	-7.182748395560000221e-01	1.846669473099999959e+00	-3.219225358350000232e-01
7.013999999999999773e+02	1.622542269442416724e-02	6.400000000000000355e+00	2.412756826438417193e+02	2.161912621228934128e-01	-1.146222917700000039e+02	2.671184597600000075e+02	-4.680251104799999951e+01
7.013999999999999773e+02	-1.622542269442416724e-02	6.400000000000000355e+00	1.750440472082394283e+00	2.071924201794096421e-01	-7.761854893999999838e-01	1.925989215760000040e+00	-3.497496186729999734e-01
7.013999999999999773e+02	1.605001271932243734e-02	6.400000000000000355e+00	2.444869957445854993e+02	-3.069382857521087082e+00	-1.127873859989999943e+02	2.692662374669999963e+02	-4.604368299530000286e+01

How are we going to use or deal with the data?



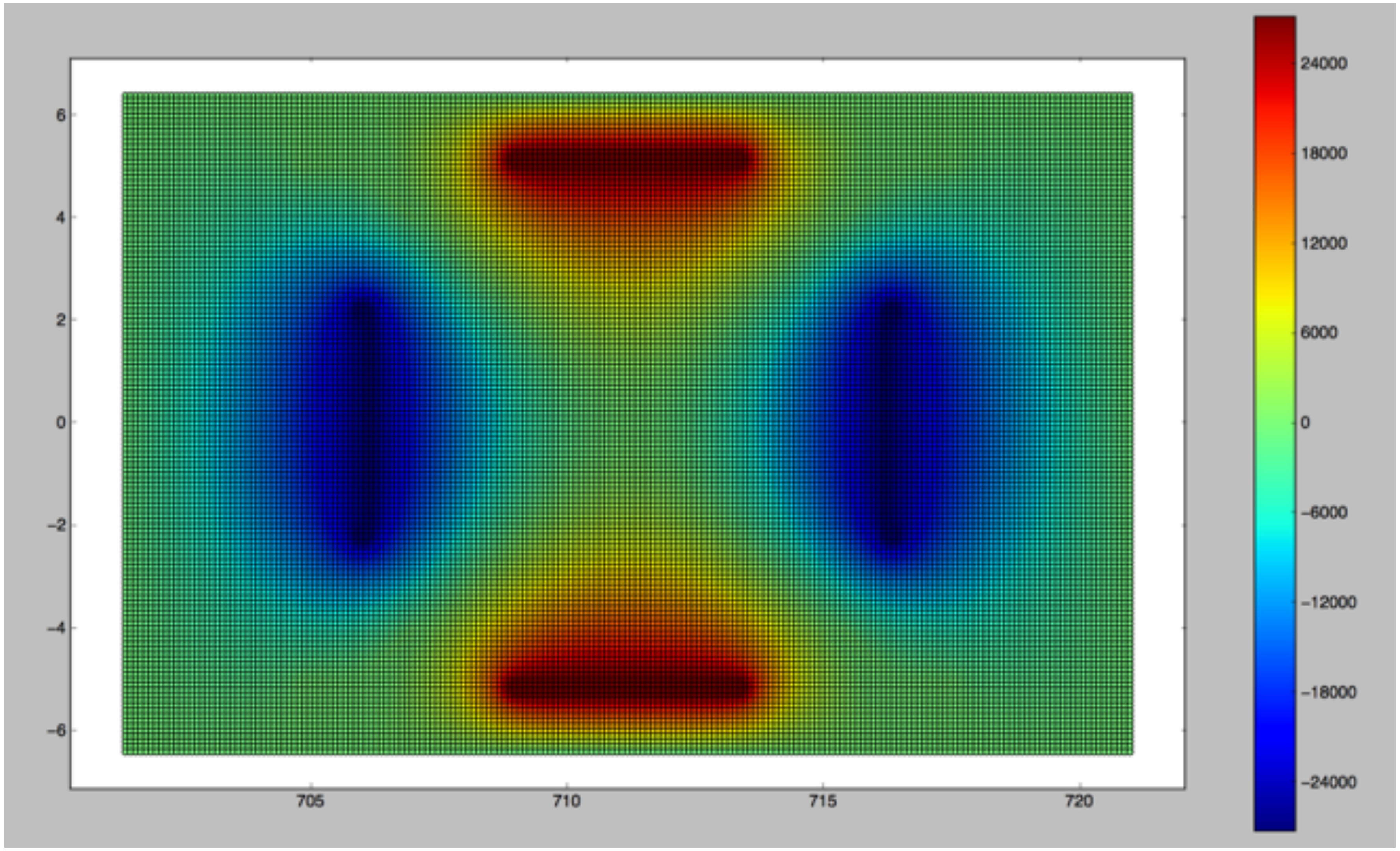
EndUS:
(2° segment, plate end locates at the middle=> less than 500 MB)

Middle
(consider the azimuthal symmetry=> 5 MB)

EndDS
(2° segment, plate end locates at the middle => less than 500 MB)

Electric Field Map—3D from OPERA 3D

Middle part => a 2D map but with 3D field information



see elog: https://muon.npl.washington.edu/elog/g2/Vacuum+chambers/327

More electric field results will be presented on Saturday's talk.

Fast Rotation Analysis—things to do

- E821 energy-time correlation in the bunch *(see Bill's talk docdb=3955)*
- Analyze the fast-rotation data from beginning time: yes or no
- Detailed physical and mathematical process about fast rotation analysis
- Goodness of two methods of fast rotation analysis
- Accuracy of Electric field
- Electric field correction: better or not

Backup

Motivation: Muon g-2 experiment $\vec{\omega}_a$

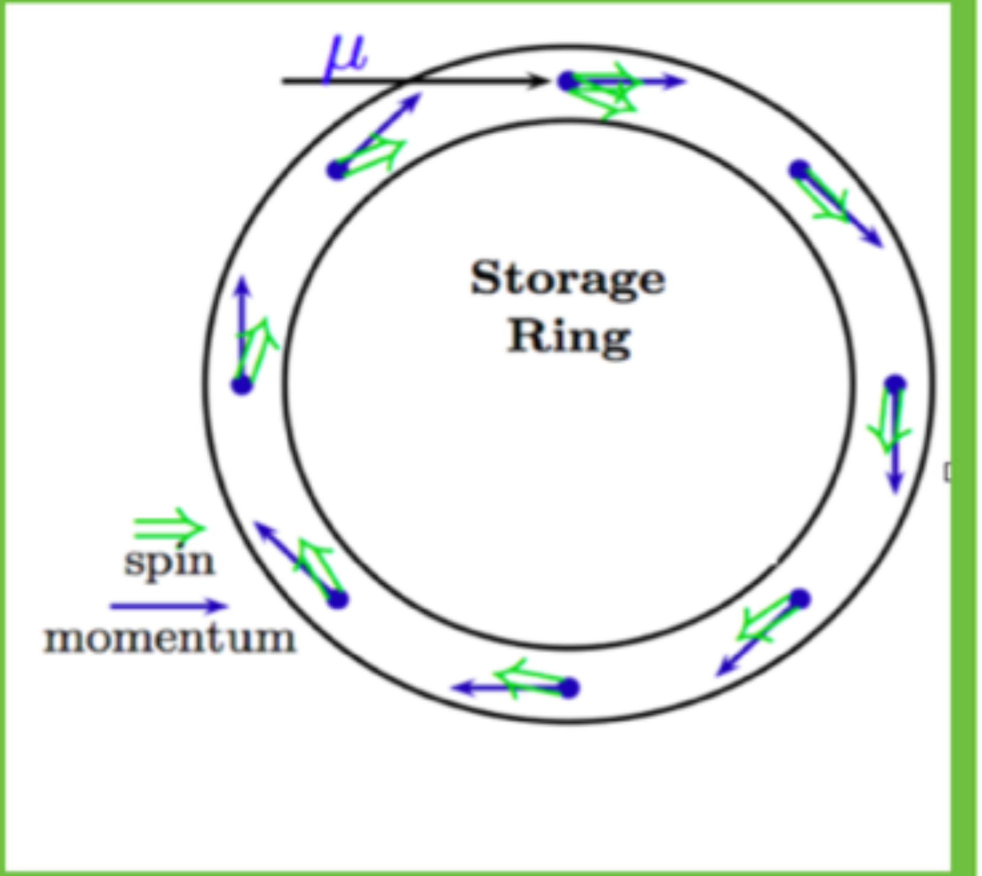
Spin rotation of a muon in a magnetic field

- spin precession frequency

$$\vec{\omega}_S = -\frac{qg\vec{B}}{2m} - \frac{q\vec{B}}{\gamma m}(1-\gamma)$$

- Cyclotron rotation frequency

$$\vec{\omega}_C = -\frac{q\vec{B}}{m\gamma}.$$



$$\vec{\omega}_a = \vec{\omega}_S - \vec{\omega}_C = -\left(\frac{g-2}{2}\right)\frac{q\vec{B}}{m} = -a_\mu \frac{q\vec{B}}{m}.$$

Motivation: Electrostatic focusing & E field correction

Electrostatic focusing

- spin precession frequency

$$\vec{\omega}_S = -\frac{q}{m}\left[\left(\frac{g}{2} - 1 + \frac{1}{\gamma}\right)\vec{B} - \left(\frac{g}{2} - 1\right)\frac{\gamma}{\gamma+1}(\vec{\beta}\cdot\vec{B})\vec{\beta} - \left(\frac{g}{2} - \frac{\gamma}{\gamma+1}\right)\left(\frac{\vec{\beta}\times\vec{E}}{c}\right)\right]$$

- Cyclotron rotation frequency

$$\vec{\omega}_C = -\frac{q}{m}\left[\frac{\vec{B}}{\gamma} - \frac{\gamma}{\gamma^2-1}\left(\frac{\vec{\beta}\times\vec{E}}{c}\right)\right]$$

$$\vec{\omega}_a = -\frac{q}{m}\left[a_\mu\vec{B} - a_\mu\left(\frac{\gamma}{\gamma+1}\right)(\vec{\beta}\cdot\vec{B})\vec{\beta} - \boxed{\left(a_\mu - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c}}\right]$$

- Muon momenta differ from the magic momentum

$$\omega_a' = \omega_a\left[1 - \beta\frac{E_r}{cB_y}\left(1 - \frac{1}{a_\mu\beta^2\gamma^2}\right)\right],$$

where $\omega_a = -a\frac{Qe}{m}B$. Using $p = \beta\gamma m = (p_m + \Delta p)$, after some algebra one finds

$$\frac{\omega_a' - \omega_a}{\omega_a} = \frac{\Delta\omega_a}{\omega_a} = -2\frac{\beta E_r}{cB_y}\left(\frac{\Delta p}{p_m}\right).$$

The effect of the radial electric filed reduces the observed frequency from the simple frequency ω_a

$$\boxed{C_E = \left(\frac{\omega_a' - \omega_a}{\omega_a}\right)_E = \left(\frac{\Delta\omega}{\omega_a}\right)_E}$$

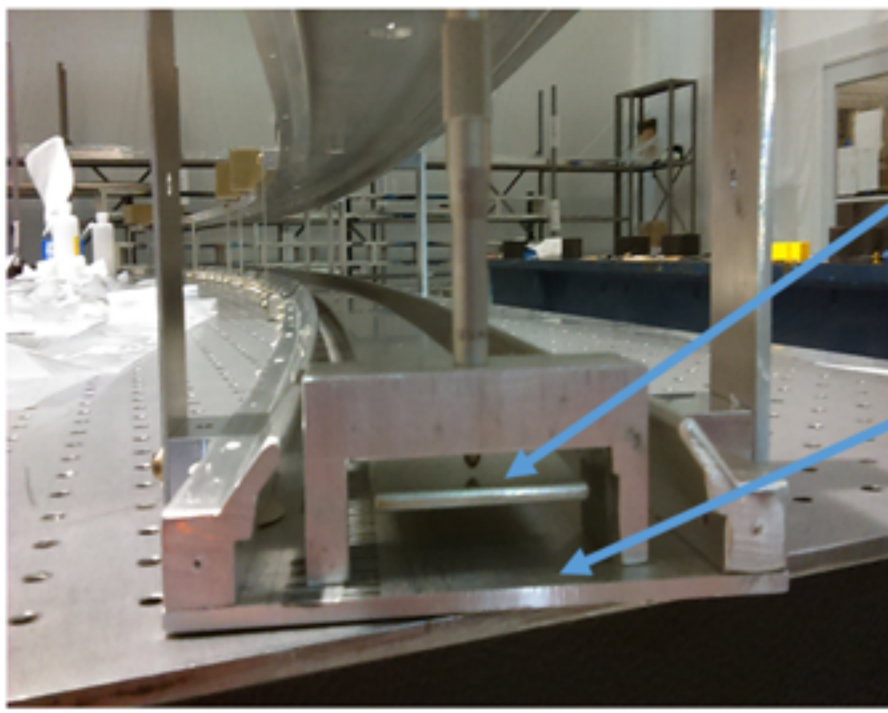
Backup— Q1 outer plate vertical alignment result

outer standoff	position	upper (mm)	lower (mm)	A'	B'	C'	D'	deviation (mm)
1	3	4.12	3.86	349.96	345.84	286	282.14	0.13
2	32	4.66	3.86	350.14	345.48	285.9	282.04	0.4
3	61	3.8	4.12	349.36	345.56	286.36	282.24	-0.16
4	71	3.8	4.12	349.36	345.56	286.36	282.24	-0.16
5	95	3.94	4.06	349.32	345.38	285.72	281.66	-0.06
6	125	4.02	4.26	349.24	345.22	285.74	281.48	-0.12

- We only measure once for positions where we have standoff 3 and 4, since they are close each other.
- For standoff 2 the upper value has large deviation, this dues to the twist of the cage, not the plate's problem.
- the alignment has a result: less than ± 0.2 mm

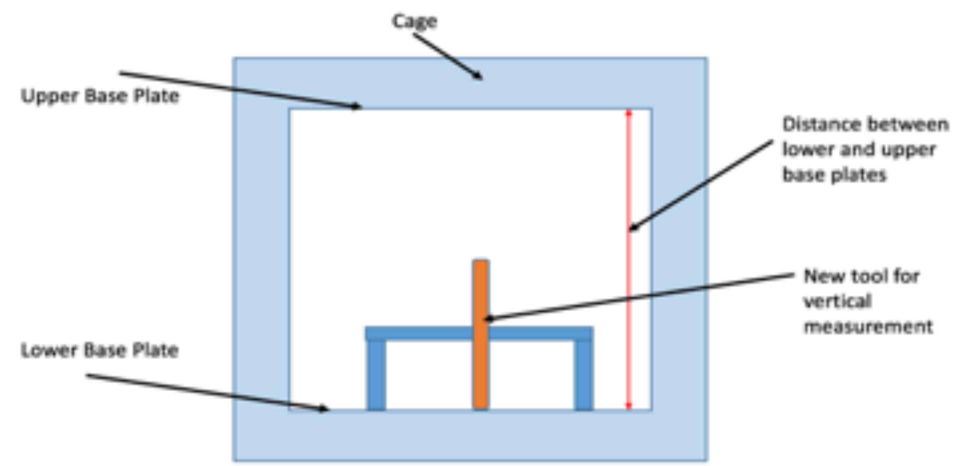
Quad Plate Alignment—Principle and Ideas

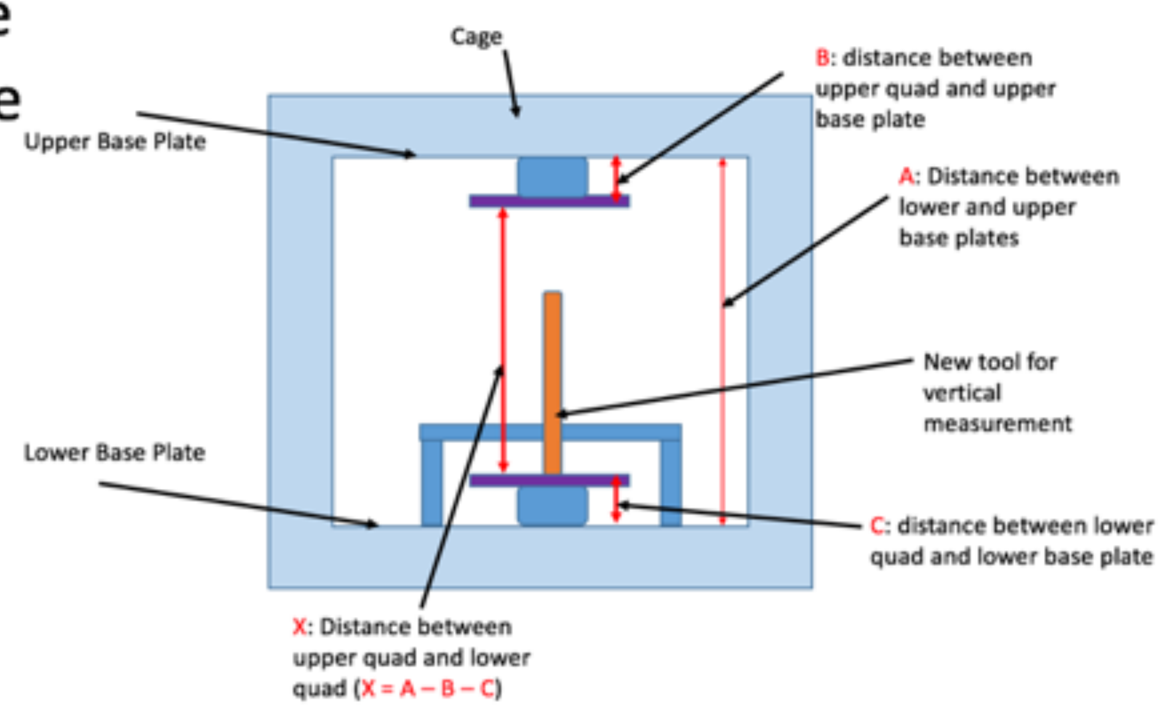
- Micrometer Tool



Lower
Quad plate

Lower
base
plate

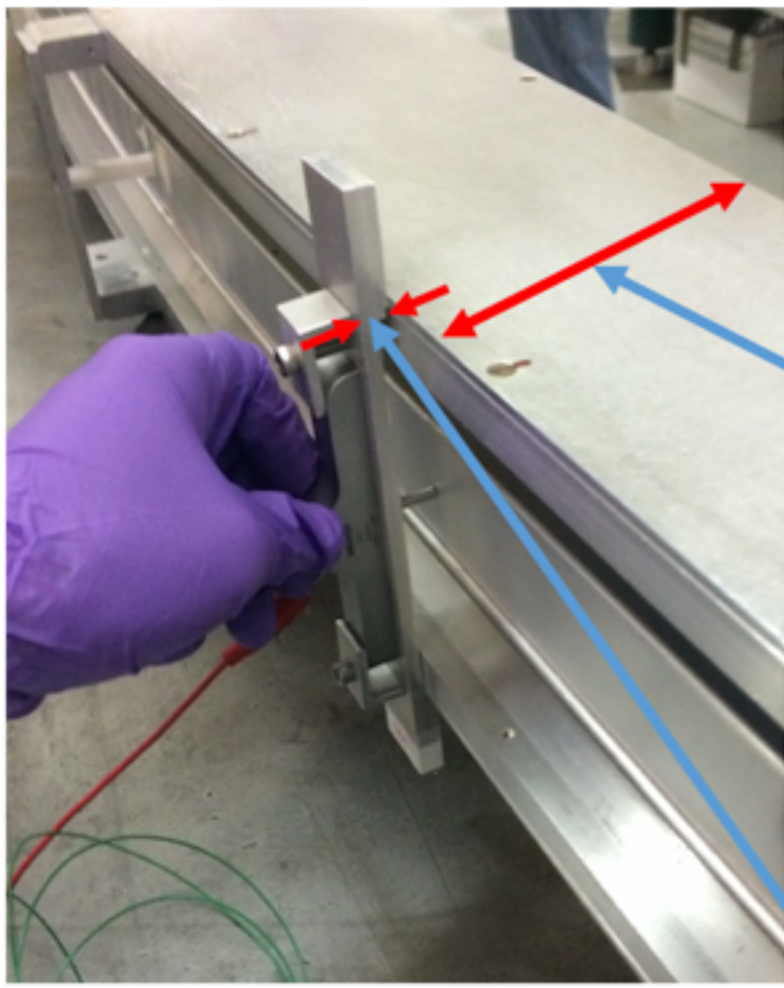




A special tool for vertical
electrodes alignment

Quad Plate Alignment—Principle and Ideas

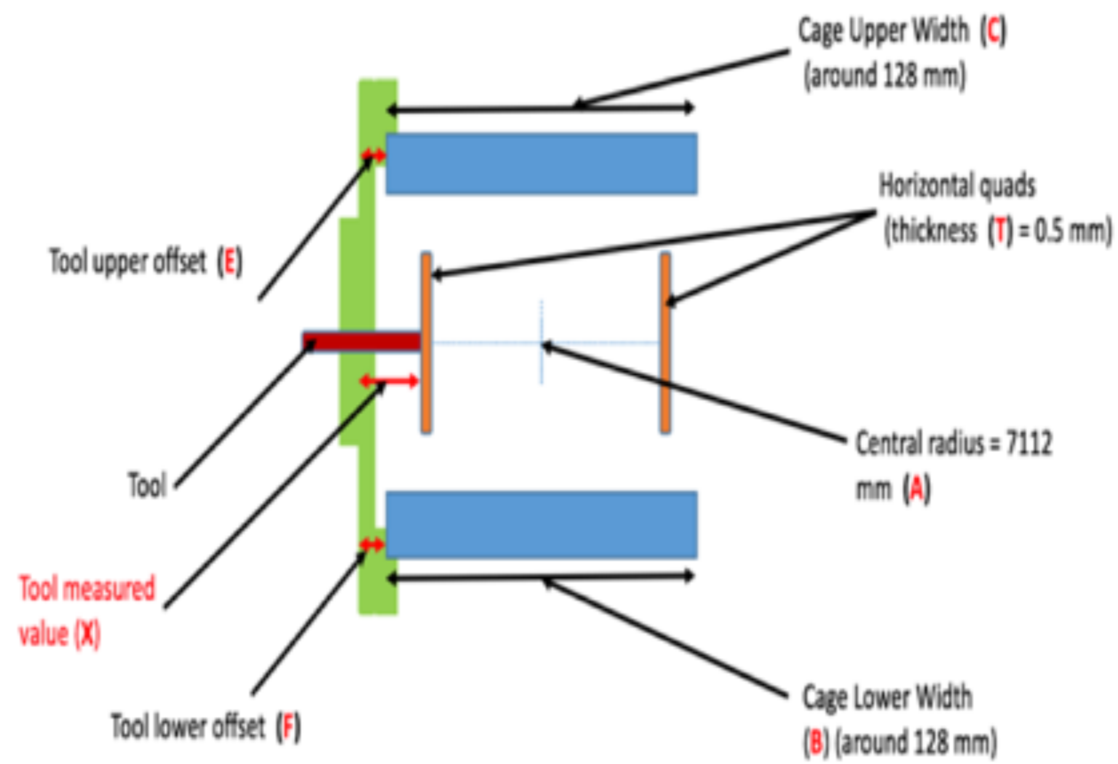
- **Micrometer Tool**



A special tool for horizontal electrodes alignment

Cage upper surface width

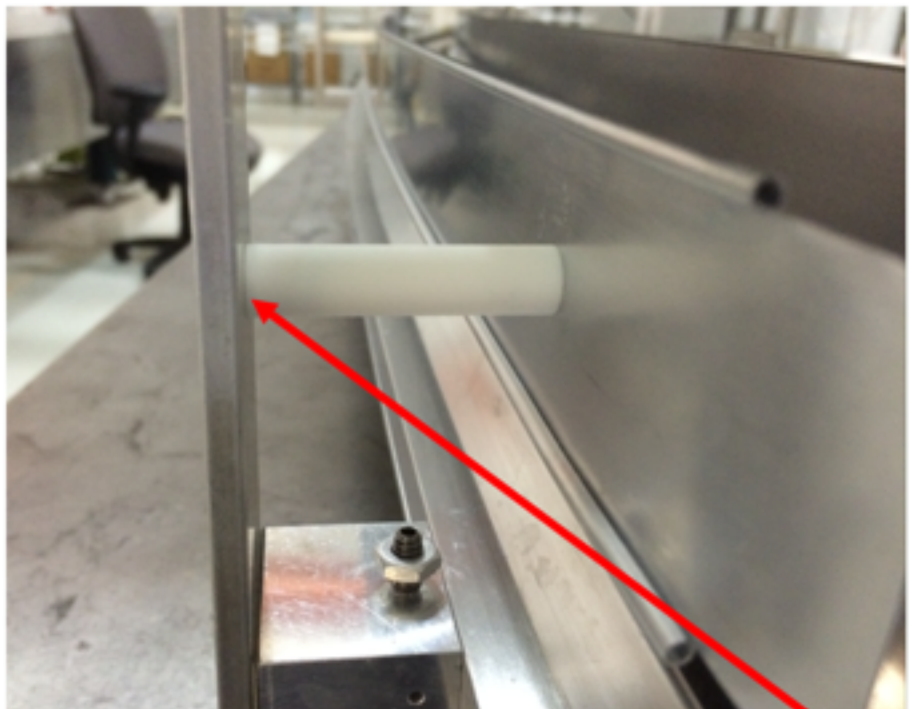
Tool Offset

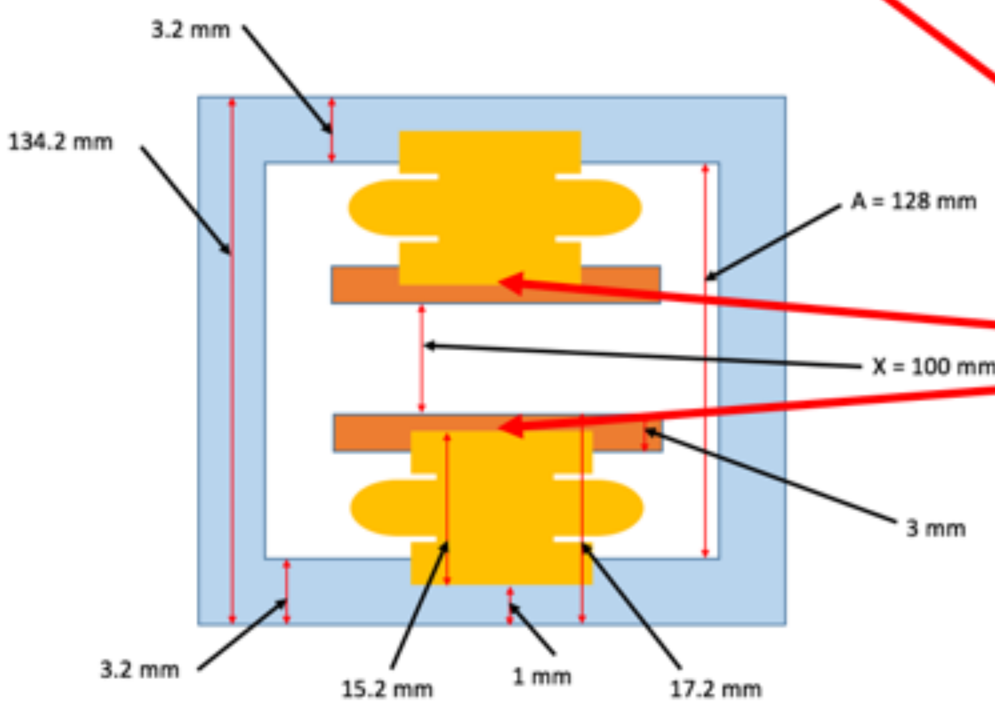


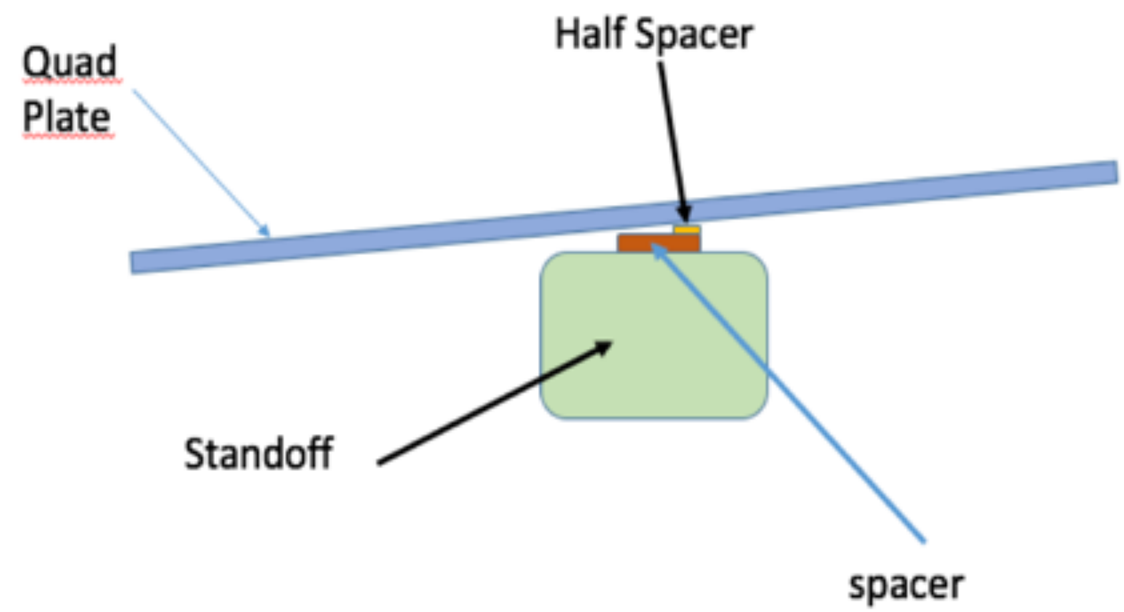
$$\text{Outer\_Quad\_Radius} = A + [(B+C)/2]/2 - [X-(E+F)/2+T]$$

$$\text{Inner\_Quad\_Radius} = A - [(B+C)/2]/2 + [X-(E+F)/2+T]$$

Quad Plate Alignment—Principle and Ideas

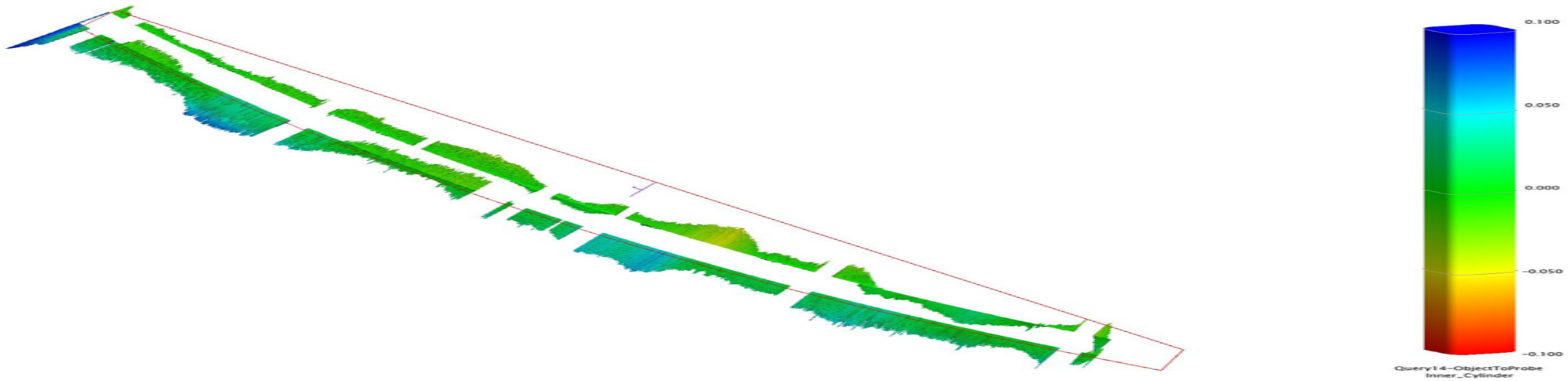




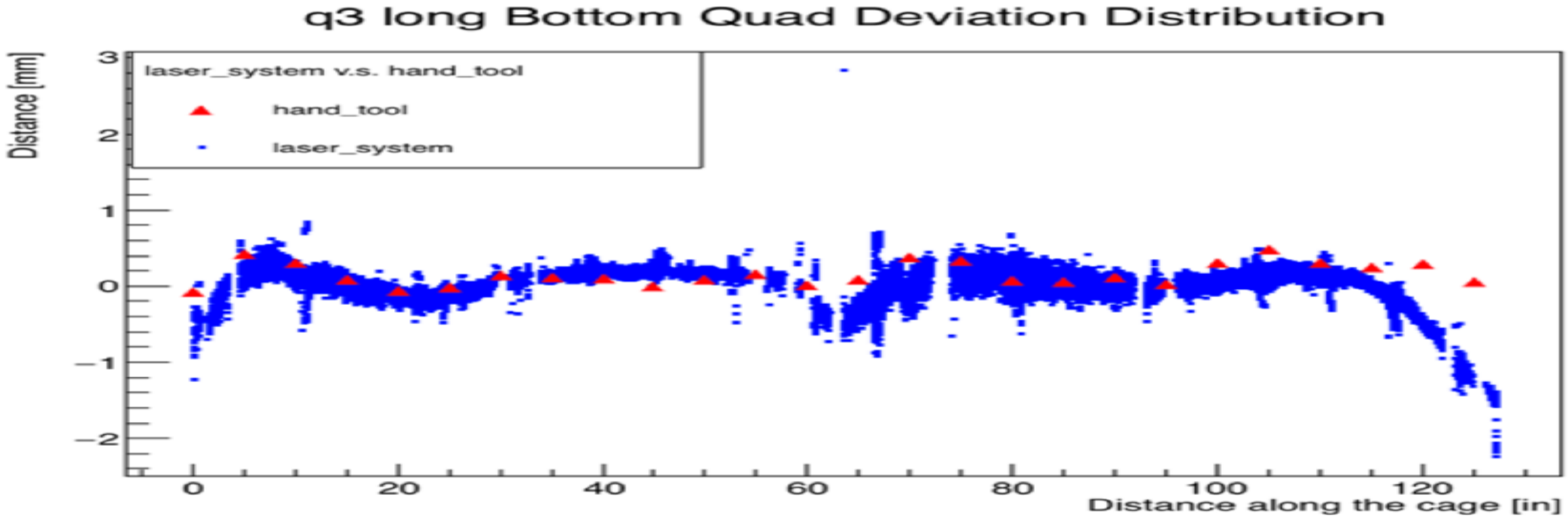


Spacer or half spacer will go these places if needed.

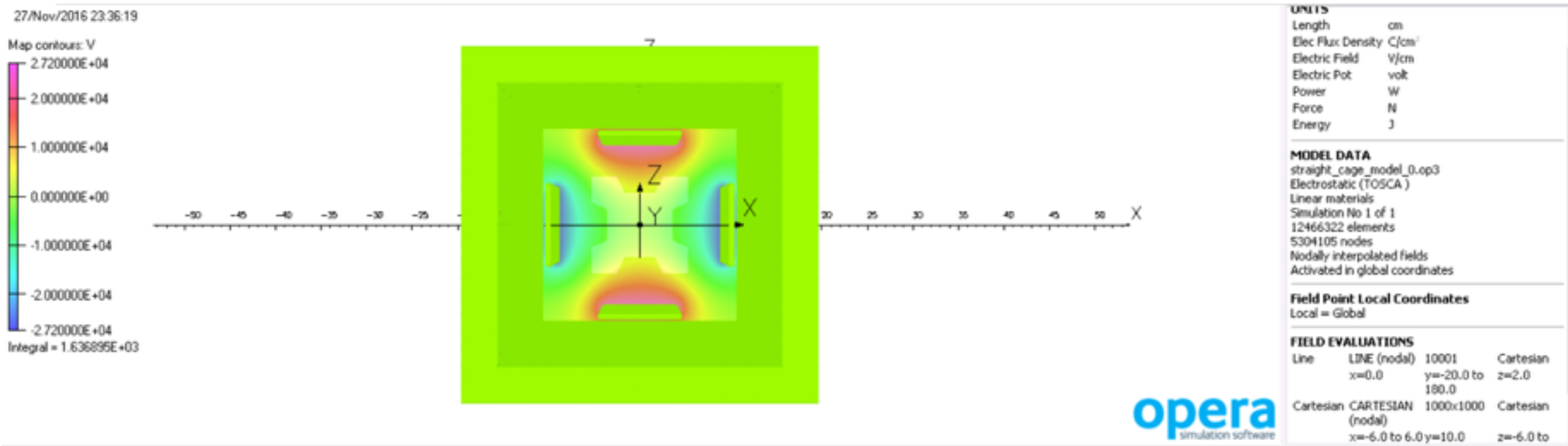
Quad Plate Alignment—Laser system v.s. Micrometer Tool



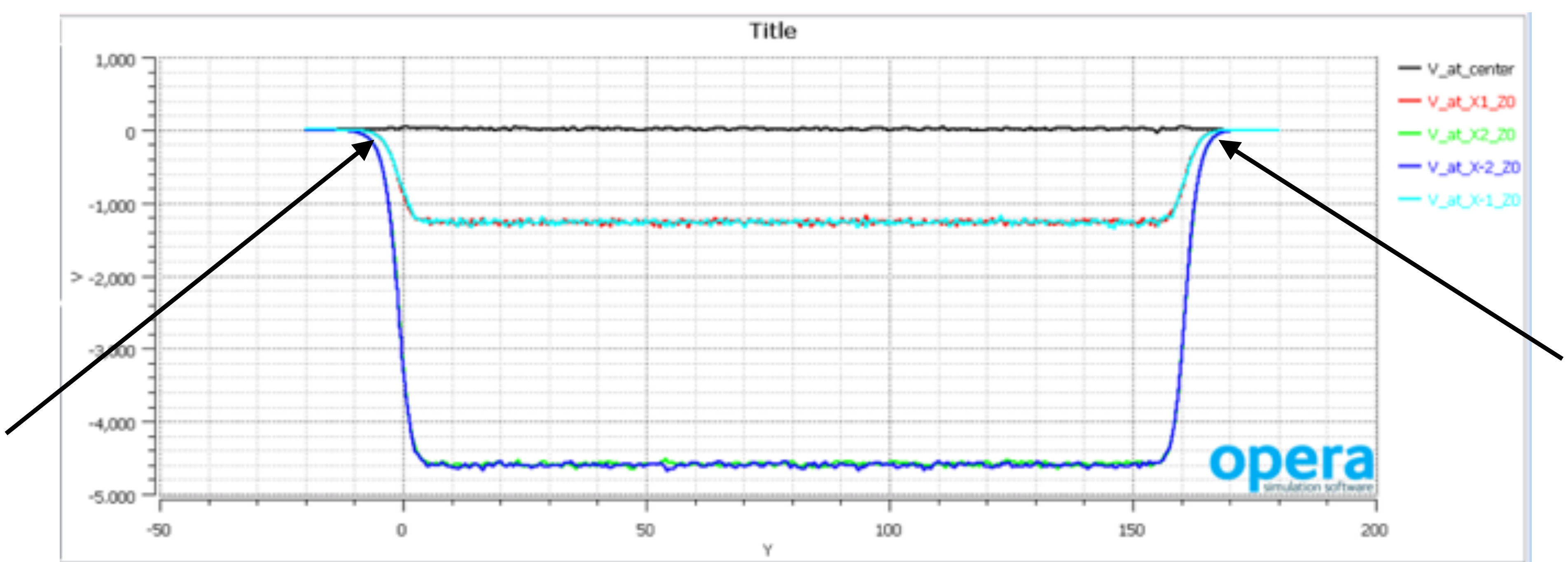
Results from laser scan and hand tool (comparison):



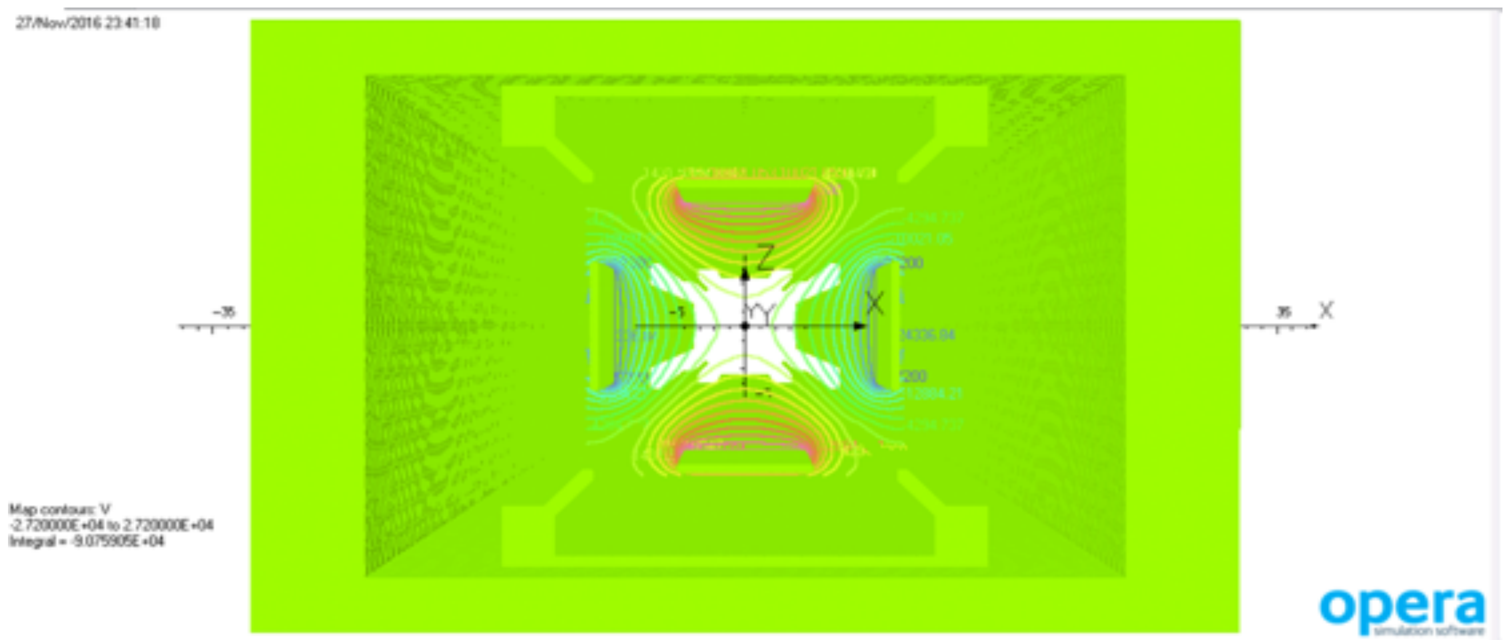
Electric Field Map—End effect



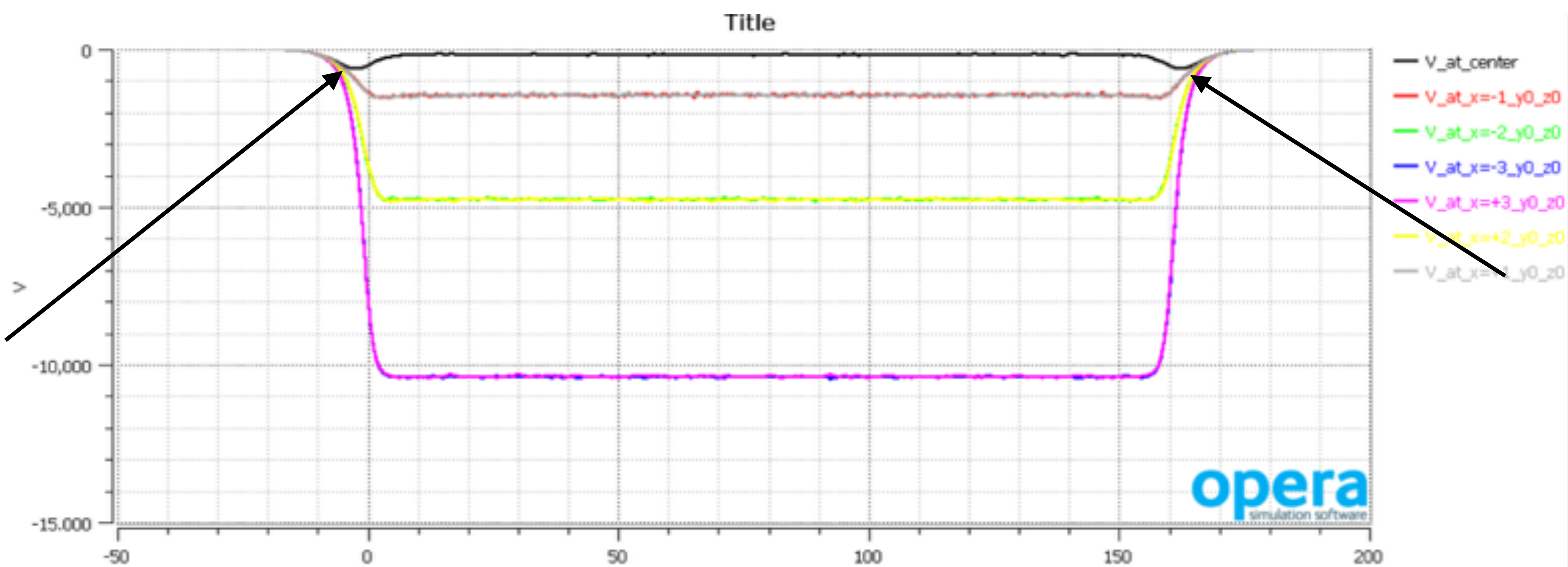
RZ Axis Symmetry



Electric Field Map—End effect



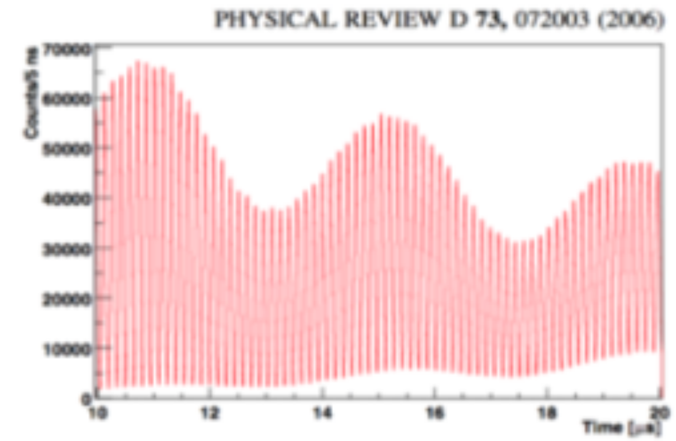
Asymmetric cage and chamber on RZ axis



Minimized Chi2 Method: Principle

Two set of bins:

Radial bins (i) (Lx=90 mm)
(i.e., 50 bins w/width=1.8mm)



Time bins (j) (positron count histogram)

- f_i: the content of the radial bin i, fraction of the beam oscillating around radial bin i
- N_j: $(N(j)_{obs})$ counts in time bin j
- β_{ij}: contribution from radial bin i to the counts in time bin j
- C_j: $(N(j)_{exp})$expected counts in time bin j
- Z_j: weighting factor which should equal to C_j

$$\chi^2 = \sum_j \frac{(N_j - C_j)^2}{Z_j} = \sum_j \frac{(N_j - \sum_i f_i \beta_{ij})^2}{Z_j}$$

Partial time Fourier Transform method: idea

- Fourier Transform Algorithm: calculates the cosine Fourier intgral using data available for a given detector and the first approximation for the initial time for the detector.

$$Re\Phi(f, t_s; t_m) = \int_{t_s}^{t_m} F(t) cos 2\pi f(t - t_0) dt$$

- $F(t)$: fast rotation signal, $F(t) = \frac{S(t)}{Ne^{-t/\tau}[1+Acos(\omega_a t+\phi)]}$ (ratio of the actually observed signal to the fit function discribing this signal), or $F(t) = \int df \cdot A \cdot F(f) cos\omega(t - t_0), \quad (t > t_0)$
- $\Phi(f)$: Fourier transform of the known signal $F(t)$

(Please see NIM A 482 (2002) 767775)